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Estimating and modelling the wind resource of Hungary

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Abstract

Among renewable energy resources, wind energy utilisation increased most intensely during the last decade. The sudden and widespread wind technological developments raised the question of the effectiveness of wind energy utilisation in moderate wind regions, such as Hungary. In order to support the European Union (EU) and national governmental efforts and to facilitate initiatives on renewable energy consumption, a research started on estimating and mapping the potential wind resources of the country.

Keywords: Renewable energy resources; Wind climate; Wind energy; Wind profile; Wind field modelling; Atmospheric stability

Contents

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1. Introduction

The utilisation of wind energy has been increasing around the world at an accelerating pace. However, the development of new wind projects continues to be hampered by the lack of reliable and accurate wind resource data in many parts of the world. Such data are needed to enable governments, private developers and others to determine the priority that should be given to wind energy utilization and to identify potential areas that might be suitable for development.

Hungary's traditional coal-dominated energy structure is changing slowly. Since Hungary joined the European Union (EU) in 2004, special efforts have been declared by the Hungarian government to facilitate the use of renewable energy resources. In order to fulfil the expectation of the EU, until 2010 Hungary would like to double the recent 3.6% share of renewable energy resources in the total primary energy consumption. Unfortunately, Hungary is not one of the countries with windy climate. However, because of the shortage in traditional fuel resources, the rising energy costs and the unbalanced export–import ratio of energy supply, it is necessary to consider and review the use of potential wind energy resources in this region.

In response to the need for a new wind resource assessment of Hungary, a research started on clarifying the possibilities of wind energy utilisation in the country. Complex wind energy research has been carried out, wind atlas of the region has been created and wind energy map of Hungary has been compiled using a mesoscale wind model according to the European recommendations.

2. Wind climate of the region

Hungary occupies the low-lying areas of the Carpathian basin. The country is predominantly flat, two-thirds of the territory consist of plains below 200 m. Furthermore, the ratio of the hilly and mountainous terrain lying higher than 400 m is approximately 2% of the whole area of the country. There are three basic topographies: (1) the low-lying regions of the Great Plain in the southeast and the Little Plain in the northwest; (2) the northern mountain ranges, which include Hungary's highest peak (the 1015 m high Kékesteto); (3) the hilly regions of Transdanubia in the west and southwest.

The latitudinal extension of the country—less than 3° (45°45′–48°35′)—is not responsible for significant climatological differences between the northern and southern areas. Hungary had not been the subject of extensive wind resource studies in the last century. However, several studies were carried out analysing the surface and upper-air wind records spanning several decades. Therefore, based on hourly wind speed averages of the latest 6-year-long data sets of 29 Hungarian climate stations, supplementary wind characteristics were calculated applying a methodology corresponding to the *European Wind Atlas* [1], the Wind Atlas of Hungary was compiled, and the main energetic parameters were analysed [2].

Based on wind data of 29 Hungarian climate stations (which was converted to standard measuring height: 10 m), the mean wind speed ranges between 1.47 m s^{-1} (Jósvafo) and 4.05 m s^{-1} (Szentkirályszabadja). Therefore, Hungary can be considered as a moderate windy region [3] corresponding to the European Wind Classification.

Choosing the six most representative climate stations [4] (Table 1), the main characteristics of the Hungarian wind climate are summarised in the following diagrams.

In Fig. 1, the relative frequencies of wind directions are demonstrated over Hungary based on a 6-year-long data series of the six stations. In the western and central part of Hungary the north–north-western, while in the eastern part of the country the north–north-eastern wind directions are the most frequent. The relative frequency of the dominant wind direction is low, ranging between 12.6% (Pécs) and 23.0% (Sopron). However, the frequency of calm periods in some regions is relatively high; the minimum is 1.39% (in Kékesteto, at 25.07 m height), while the maximum is 6.1% (in Szeged, at 8.62 m height).

Relative frequencies of 2–3 m s^{-1} winds are the highest (Fig. 2); thus Hungary can be characterised as a moderate windy country. Frequency distribution of the wind speeds greater than 10 m s^{-1} is very low, less than 0.5%. In some stations, the frequencies of calm

Table 1
Geographical locations and main characteristics of wind measurements at six representative Hungarian climate stations

Station	Latitude	Longitude	Height (m)	Instrument height (m)	Annual average (m s^{-1})	Standard deviation (m s^{-1})
Budapest	47°26′	19°11′	138.0	14.68	2.53	1.60
Kékesteto	47°52′	20°01′	1010.3	25.07	4.11	2.22
Nyíregyháza	47°58′	21°53′	140.9	27.00	3.52	2.04
Pécs	46°00′	18°14′	201.8	21.37	3.28	2.00
Sopron	47°41′	16°36′	233.0	18.40	3.92	2.47
Szeged	46°15′	20°06′	81.9	8.62	3.06	2.08

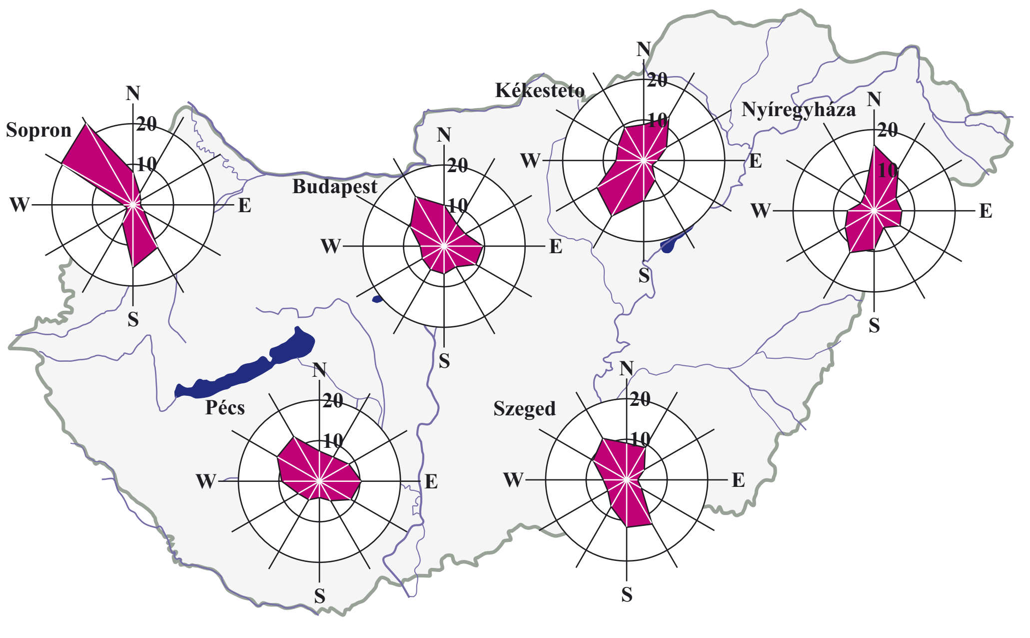


Fig. 1. Relative frequencies (%) of wind directions over Hungary.

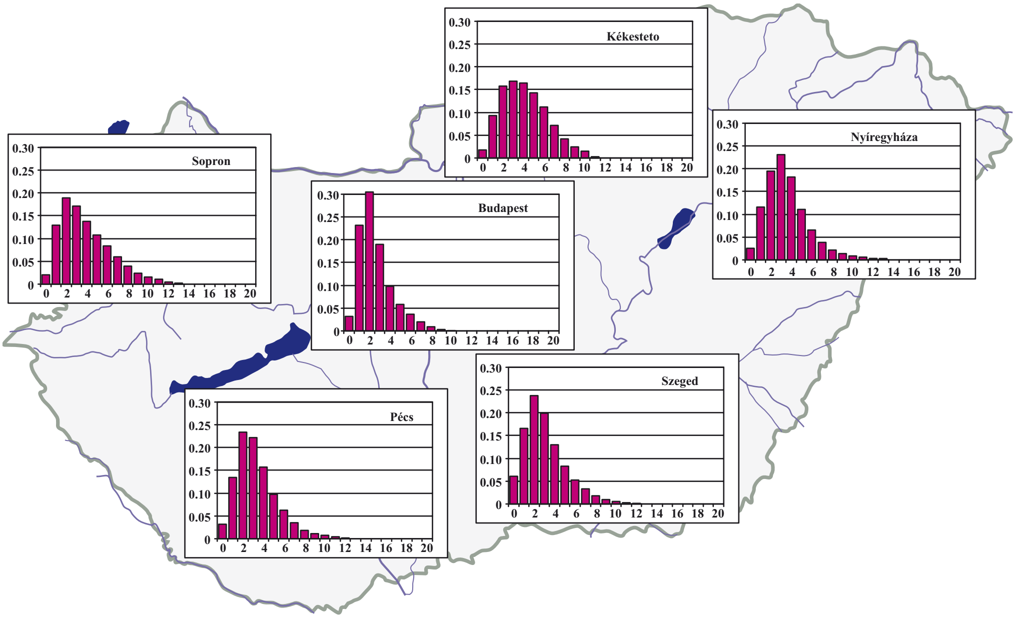


Fig. 2. Frequency distributions of measured wind speed over Hungary.

periods are relatively high. For instance, in Nyíregyháza (at 27.00 m height) the relative frequency of calm periods is greater than 7.4% in January, while in Szeged (at 8.62 m height) it is nearly 8.5% in August.

The mean wind speed and the cube of the mean wind speed (Fig. 3) show definite annual and diurnal cycles. The annual maximum occurs in spring, while the minimum was found at the end of summer (in August). The range of annual variability of wind speed is 1–2 $m\,s^{-1}$. The annual cycles of cubic wind speed have larger amplitudes, reaching 100 $m^3\,s^{-3}$.

3. Vertical wind profile estimations and stability conditions

Optimal siting of wind power stations requires proper information on wind profile and atmospheric stability. Therefore, as a part of our research project a case study was carried out on wind profile estimation concerning different stability conditions. Collaborating with the CHIOTTO EU-5 framework project wind profile measurements were carried out near the village Hegyhátsál [5], at a site of the southwestern part of Hungary (46.96°N, 16.65°E). Wind speed and wind direction have been observed at four levels since 1994 [2,6]. Although our data set includes bias caused by the shelter and wind field perturbation effects of the specially shaped tower [7], detailed profile analysis and profile fitting provide appropriate information about the vertical structure of the air flow. An 8-year-long (1995–2002) time series of station Hegyhátsál were involved in the analysis. Using the monthly averaged wind speed data of each measuring level (Fig. 4), the maximum values appeared in March while the minimum was found in October (at 10 m height) or in August

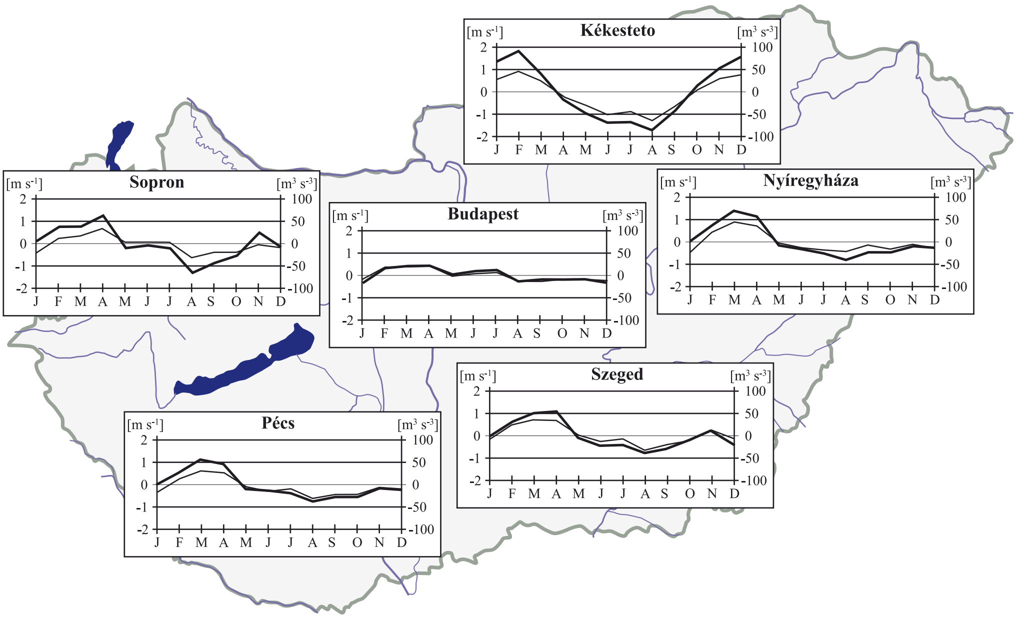


Fig. 3. Annual distribution of mean (thin line) and cubic (thick line) wind speed over Hungary.

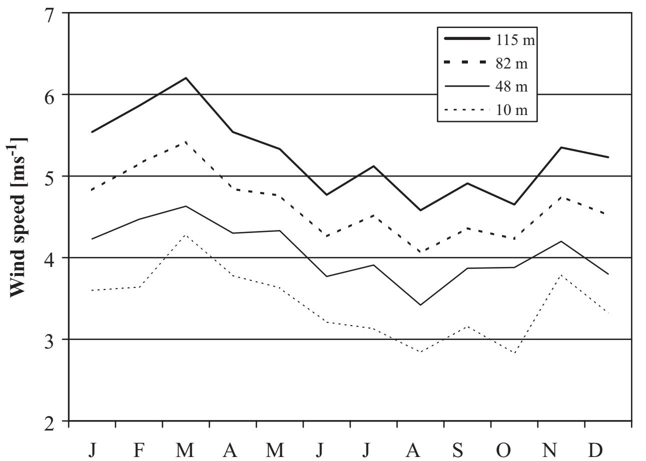


Fig. 4. Annual distribution of measured wind speed at different observation levels in station Hegyhátsál.

(at higher levels). Furthermore, the well-known annual cycle of wind speed slightly increases with height. These results are in good agreement with the main climate characteristics of this region.

The diurnal distributions of wind speed measured at each level are demonstrated in Fig. 5. In general, on the lowest 50 m level the daily maximum wind speed can be observed at approximately 2:00 p.m., while the minimum occurs during dawn [8,9]. These are

justified by the wind measurements, at 10 and 48 m heights the highest wind speed values occur around noon, while at 82 and 115 m levels an opposite daily distribution was found with maxima during night-time.

In order to estimate potential wind energy resources of the Hegyhátsál area, it was essential to analyse not only the vertical wind but also the vertical temperature profile. A 1-year-long (1998) data set of the calculated Monin–Obukhov length [10] was used to classify wind speed measurements depending on atmospheric stability. In Fig. 6, the daily distributions of atmospheric stability for each season are demonstrated. Significant seasonality was found between the relative frequencies of stable and unstable atmospheric stratification. Relative frequency of unstable stratification was much less at night in spring and summer than in autumn and winter. Furthermore, in winter at daytime, generally stable stratifications were observed.

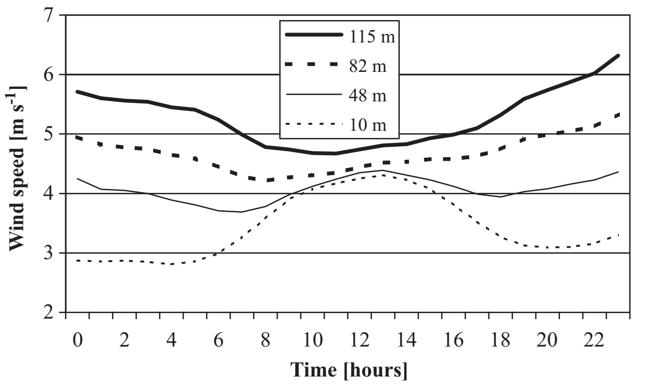


Fig. 5. Diurnal distribution of measured wind speed at different observation levels in station Hegyhátsál.

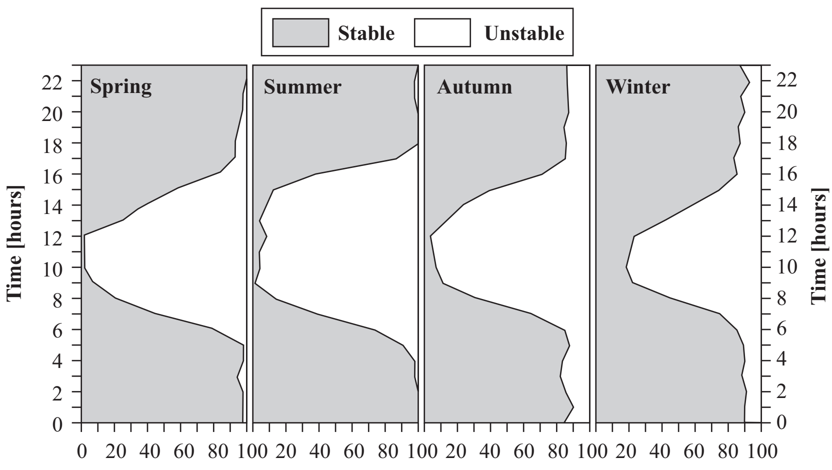


Fig. 6. Diurnal distribution of seasonally observed stability conditions at station Hegyhátsál.

Next, empirical wind profile equations were evaluated depending on atmospheric stability [4]. In cases of unstable stratification, all the analysed wind profile equations underestimate, while in stable cases they overestimate the measured wind speed values of higher levels (82 and 115 m).

4. Wind power map of Hungary

In order to estimate the stream field modification effects of topography and roughness, the Wind Atlas Analysis and Application Program (WAsP, developed at Risø National Laboratory, Roskilde, Denmark) was applied. WAsP [11] is a linear spectral model for near-neutral boundary layer flow over complex terrain, which can be used to analyse raw time series, to estimate the wind climate at any site using digitised topographical, roughness and shelter maps, and to extrapolate horizontally and vertically the measured wind data.

The WAsP model has been tested using wind data of 29 Hungarian synoptic meteorological stations and the wind profile measurements of Hegyhátsál. Furthermore, the adaptability of the model has been verified for Hungary [4]. In order to analyse the most important characteristics of the available wind power, field modification effects of topography and roughness were evaluated, horizontal and vertical extrapolation of the measured wind data was carried out in several case studies for different regions of the country [3,7]. Finally, simulated mean wind speed and available wind power maps of Hungary were compiled (at 10, 40, 80 and 120 m height) using the WAsP and the European Digital Terrain Models. Based on these maps, the potential wind energy resources of our country are reviewed, and Hungary has been regionalised from the viewpoint of wind energy utilisation.

The simulated mean wind speed values as well as the topography are in good agreement with the structure of mean available wind power field [4,7]. Simulated mean wind speed and available wind power at 120 m height are one and a half times and three times greater than at 10 m height, respectively. As height above ground level increases, the difference between the potential wind energy of the most and the least windy regions of Hungary is

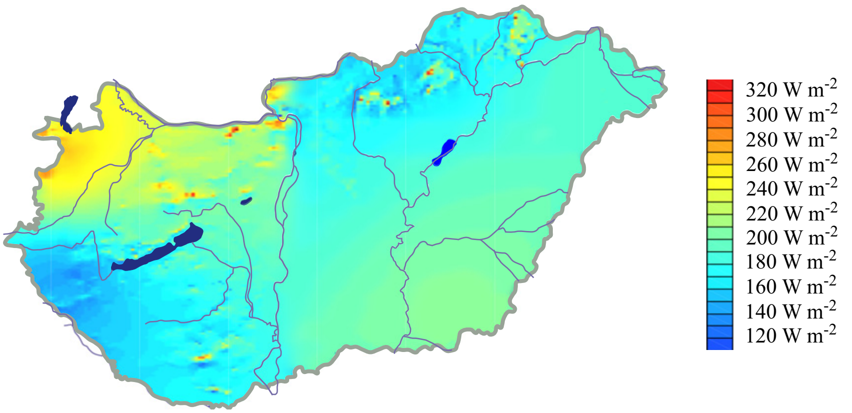


Fig. 7. Simulated available wind power map of Hungary at 120 m height considering the wind field modification effects of topography.

getting larger. Fig. 7 illustrates the simulated available wind power field at 120 m height, considering the stream field modification effects of topography. Available wind power values show large spatial differences over the country. Over small horizontal distances, considerable differences are found mainly in the mountains.

5. Conclusions

In this paper, results of complex wind energy research for Hungary were presented. First, the main wind climate parameters of the region were summarized according to the European recommendations. The structure of the vertical wind profile and the relationships between atmospheric stability and different errors of empirical wind profile formulas were analysed using the data of four measuring levels. Finally, wind energy map of Hungary has been simulated and compiled using the Wind Atlas Analysis and Application Program.

The most suitable region for wind energy utilisation is the north-western part of the country; however, the south-eastern region of Hungary also possesses considerable wind energy resources.

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